maximum age are more apt to be males. Whatever of adaptational effect there may be detected in this arrangement is probably, however, not of great importance. The major share of the reproductive activity of the chiton population is carried on by individuals between five and seven years old; they are more numerous than the older ones, and the volume of the gonad is in them relatively greater than at other ages. The proportion of the sexes is here very nearly as 1:1. These animals are usually found close together in groups of a dozen or more, under stones or in crevices.

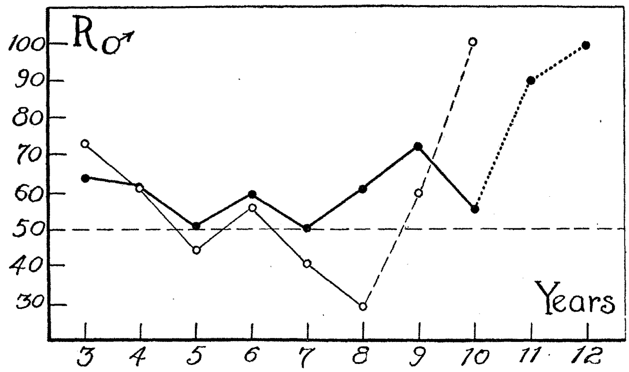

FIG. 4. VARIATIONS IN THE PROPORTION OF MALES IN DIFFERENT AGE-GROUPS OF CHITON TUBERCULATUS

● = Great Sound; ○ = Cross Bay.

Summary.—Curves have been derived which illustrate the extent to which the rate of growth and the duration of life of Chiton tuberculatus may be modified in differing natural environments at Bermuda; attention is also called to variations found in the proportion of the sexes, in different year-groups.

[1] Contributions from the Bermuda Biological Station for Research, No. 97.

[2] Cf. Crozier, W. J., and Arey, L. B., *Amer. Jour. Physiol., Baltimore*, **46**, 1918, (487–492). Arey and Crozier, (in press).

[3] Heath, H., *Zool. Anz., Leipzig*, **32**, 1907, (10–12).

THE INTERFEROMETRY OF VIBRATING SYSTEMS

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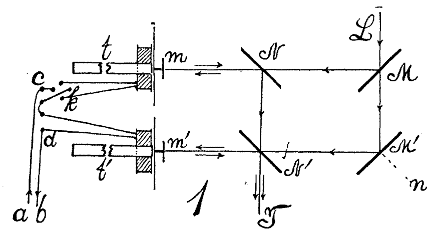
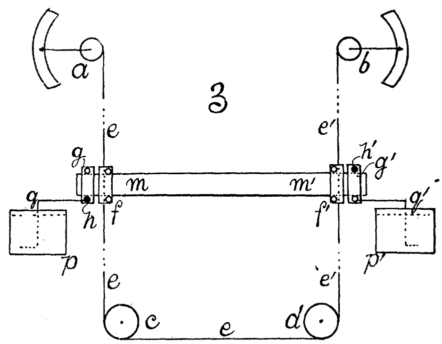
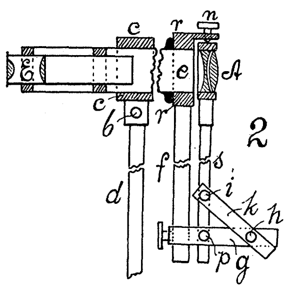
1. Introductory.—The high luminosity of the achromatic interferences and the occurrence of but two sharp fringes, make it possible to utilize them even in cases when the auxiliary mirrors vibrate. Experiments of a similar kind were

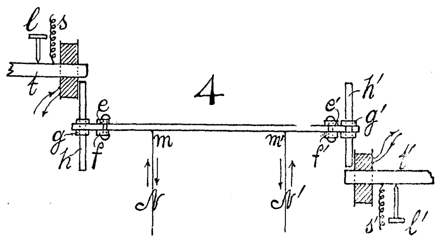
tried with telephones and the spectrum ellipses before;[1] but these fringes do not easily admit of being drawn out into a ribbon and there is usually deficient light.

2. *Apparatus.*—I began the work with two similar telephones, as shown at *t, t'*, in figure 1. Small mirrors were rigidly attached to the center of the diaphragms and each of the telephones secured on standards which admitted of adjustment around vertical and horizontal axes. The intermittent current was supplied at *a, b* from a small induction coil with a rheostat in circuit. Four clamp screws at *c, d*, were available for putting the telephone bobbins in series or in parallel. The current of one could be versed at *k*. White light, *L*, from a collimator, was reflected or transmitted by the half silvered mirrors, *M, M'*,









N, N', of the interferometer and from *m, m'*, on the telephones as indicated by the arrows. *M'* was on a micrometer with the screw on the direction, *n*. To facilitate the finding of the fringes one of the telephones *t'*, should also be on a micrometer with the screw normal to *m'*. The fringes when found are observed by the vibration telescope at *T*.

The vibration telescope is shown in vertical section in figure 2, with the ocular at *E* and the objective originally as *e*, the tube being supported on the standard, *d*, and clamp *cc*, admitting of raising and lowering and of slight rotation around the horizontal axis, *b*. The objective, *A*, has been removed and is now supported by a flat steel spring, *s*, in front of its former position.

In order that the objective may vibrate parallel to the fringes and as these appear in all angles of altitude, the special vibratory system *f, g, k, s*, has been

devised. The rod f, reaching downward (about 10–15 cm. long) is attached to a ring of the objective, rr, capable of revolving with friction around the tube of the objective and of being fixed for any position in altitude of the rod. The horizontal clamp, g, adjustably attached to the rod, f, supports the spring, s. This passes through a vertical crevice in g; it is fixed by the set screw, p, and the two oblique adjusting strips, k, on either side of g. These pieces, k, are clamped by the screws at h, and serve as holders of the two coaxial set screws at i, on either side of s, so that the objective A, may be centered relative to the tube, Ee, for any oblique position of f, which must be normal to the fringes. The vibration may frequently be considerably changed by sliding f and s in g and reclamping the system. If the objective is to be fixed, a screw at n may be depressed for the purpose.

Under all circumstances the two spots of light representing the slit, if caught objectively on a screen at T, must be nearly coincident, horizontally and vertically, when the rays at T are parallel. If these spots are too far apart the fringes will be very small or even absent.

3. Observations with telephones.—The use of two telephones soon showed itself to be unsuitable for the present purposes, for the diaphragms oscillate not merely fore and aft (as in here desirable) but around horizontal and vertical axes as well, particularly when the vibration is relatively intense. Hence the coincident slit images of the silent telephone periodically separate. This shows itself in a peculiar manner in the field of the vibration telescope. The whitish field carrying the fringe waves due to the fore and aft motion of the mirror, m, m', figure 1, on the diaphragm of the telephones, is intersected by nearly equidistant vivid white lines, normal to the waves. The latter are apt to be broken and appear only as traces between the vertical lines in question.

To account for these occurrences of the lines, it is sufficient to recall that the originally coincident identical fine slit images are vibrating through each other in some direction effectively normal to the slit. Hence these images will be seen clearly only at the elongations, when the slit images are temporarily stationary and at a maximum distance apart. Hence also the waves are absent at the lines, for here the slit images are so far apart as to eliminate the interferences.

As it made little difference how the telephones were electrically connected the diaphragms were removed and replaced by the two long strips of steel made from hack saw blades rigidly attached to the body of the telephone by a metallic arch. To approach this as near the magnet as possible forcing screws were provided at a little distance from the end of the strip. In this case the vibration of the strip and the mirror at its middle was fore and aft only and as a consequence the bright lines intersecting the field vanished completely. The arrangement of telephones, whether in series or parallel made a decided difference in the amplitude of the waves, which could be increased many times the breadth between successive fringes before the waves became turbulent and broke up.

4. *Bifilar systems.*—To utilize such a system as figure 1 to advantage it would be necessary to attune the elastic vibrators at m, m', to the same period, which should be as nearly as possible identical with the period of the source of intermittent or alternating current. As an earth inductor or a small magneto inductor (single magnet rotating in a flat coil) would have to be used in the latter case, it seemed best to convert the apparatus into a bifilar vibrator as shown in figures 3 and 4 in elevation and plan. Here mm' is a strip of thin mirror plate glass, about 32 cm. long, 1 cm. broad and 2 mm. thick, horizontal and in a position to receive the rays N, N' of the interferometer (compare figure 1). Motion of mm parallel to itself, fore and aft, will therefore produce no effect on the fringes; but any rotation around a vertical axis will be immediately apparent.

This strip of glass is supported by the bifilar system $e\ e\ e'\ e'$, made of a single thin wire. The ends of ee' are wound around the horizontal screws a, b which rotate with friction and are supplied with an index and scale, so that any amount of tension may be imparted to the wire. This passes below under the pulleys c, d, as nearly free from friction as possible, with the object of securing the same tensions throughout $e\ e'$. Flat clamps f, f' of fibre and screws, attach the strip mm' to the wire at any height, but necessarily near the middle of the vertical threads, where it receives the rays $N\ N'$.

The telephonic system consists of the horizontal soft iron screws h, h' similarly attached to mm' by the flat fibre clamps g, g', and the telephones t, t'. These were made of large flat files. The screws $l\ l'$ are used to approach the telephone magnets t, t', as near the soft iron armatures h, h' as possible, without overstepping the unstable position, in view of the tension of the tense wire e, e'. To give the vibrating system adequate damping, thin wires $q\ q'$ less that a millimeter thick, bent and dipping into lubricating oil in a small vat p, p' suffice. The fibres e, e' were about 45 cm. long and their distance apart about 29 cm. Their period and that of the vibrating telescope were made about the same, on the average about 0.2 seconds.

As a generator an earth inductor with a coil of wire 60 cm. in diameter was at first used but later replaced by a small magnetic inductor. It was turned by a small motor. To measure the average intensity of current a Siemens precision dynamometer was installed, indicating currents as low as one-tenth of an average milliampere. Periods from about 0.1 second to 0.3 second were available.

The three vibrating systems (mirror, telescope, alternator) thus all admit of an adjustment of their periods and these should be nearly the same if the elliptic system of Lissajous curves are to be obtained, which is the preferable case. A change of the tension of the wires $e\ e'$ in figures 3 and 4, or any adjustments at the telephones calls for a fresh search for fringes; but this is not difficult.

5. *Further observations.*—Without synchronism in the two vibrating systems (current and telephone) the motion of fringes obtained is practically inappre-

ciable when average currents within the order of milliamperes are treated. As soon, however, as approximate synchronism is established, the sensitiveness of the apparatus increases enormously. It is best for this purpose to vary the period of the motor of the alternate current generator by the slide rheostat If the fringes are horizontal and the objector therefore vibrating horizontally across the vertical slit image, the motion of he fringes is vertical. Hence the horizontal band of fringes in the absence of current, at once takes the form of a given Lissajous succession, with oppositions of rotations quite visible. The continuous change of these may be most conveniently accelerated or retarded by controlling the motor of the alternator with a slide rheostat. It is annoying if they leave the field while executing their gyrations, though they may always be restored by moving the micrometer. For mean tensions, the higher vibration curves 2 : 3, 3 : 4 may be obtained, both for the alternator moving at smaller and at larger periods than the vibrating mirror. To obtain them the motor running at maximum speed is gradually slowed down by means of the rheostat, when the forms appear in succession passing through the elliptic series at mean speeds.

The Lissajous curves continue to be very marked when additional resistances as high as 10,000 ohms are put into the circuit of the alternator. To obtain some idea of the smallest average current appreciable the Siemens dynamometer was put in circuit. Estimating the average current as $i = C\sqrt{\varphi}$ where C is the dynamometer constant and φ the deflection in centimeters, the current when 10,000 ohms is inserted and the magneto reduced in speed to $T = .25$ second was found to be of the average value of $i = 6 \times 10^{-6}$ amperes.

In a later and more refined adjustment the ellipses obtained with an insertion 10,000 ohms filled (as to their vertical or current axes) fully one-quarter of the field of the telescope. As little as one-tenth to one-hundredth of this would be easily appreciable with certainty, so that the minimum average current capable of detection may be estimated as well within 10^{-6} ampere. In this respect the device was somewhat disappointing. It must be remembered however that the above mirrors (mm') and appurtenances are unnecessarily heavy, and the bifilar too robust.

If one of the telephones is reversed, the fringes which showed marked vibration in the first position, frequently *ceases to show any vibration* until the ellipses in the former case are very large (small resistance in circuit). The results in such a case are uniformly consistent. The reason of this is apparent: For when the telephones are joined in series the lever mm', figure 3, is periodically rotated and released around a vertical axis and the displacement of fringes is proportional to the small angular amplitude of rotation. If, however, the telephones are connected differentially, the mirror mm', if properly adjusted, merely moves parallel to itself, fore and aft and the fringes remain stationary. More usually, however, there is a difference in the size of ellipses in the two cases.

It is for the investigation of this question that the adjustment pushing screws ll' and springs ss' (fig. 4) pulling toward the rear, the telephones being on a

vertical axis, were provided. If one of these, t for instance, is placed in a definite effective position, while t' is relatively far from its armature h', the screw l' may be gradually pushed forward diminishing the distance to the minimum. The effect of this is further to rotate mm', and if the turning of l' is cautiously done the fringes may be passed from top to bottom of the telescopic field by l' and restored to position by the micrometer. In this way it is possible to find the tension of ee' in which for one position of the commutator there is excessive motion of fringes whereas for the other there is practically no motion.

Adjusting the bifilar as to tension, there is one position or distance between h' and t' pretty sharply determinable, for which the fringe bands change to stationary ellipses in the *absence* of all current. This peculiar result is at first puzzling, but since it is quite synchronous with the period of the telescope (stationary ellipse), it is obvious that the motion of the objective is the cause of the phenomenon and that the fibers are now in unison with its period. For distances h', t', greater or smaller the ellipses soon return to bands. The effect of the alternating current on the stationary ellipse is very beautiful. It now oscillates very much like a smoke ring for one commutator position, whereas it passes in an accentuated way through all phases for the other.

Utilizing the preceding adjustment giving ellipses and bands respectively in the two positions of the commutator, many experiments were made to detect a change of phase when a large inductance is placed on both sides of one of the telephones. But in none of the experiments thus far, was any difference discernable to be attributed to the presence of the inductance.

As a tuned system responding to definite periods only, the vibration interferometer is quite sensitive, provided the average currents are of the order of several microamperes. Between the types of compound vibration curves corresponding to frequency ratios of 4/3, 3/2, 1/1, 2/3, 3/4 there is usually an unbroken band of fringes. If the ratio of periods remains fixed, the vibration curve of course remains fixed, which is the usual sharp acoustic criterion. When the ellipses (out of tune) change continuously between lines of different inclination, the passage in one direction is often gradual whereas in the reverse or return direction it is almost sudden. Linear forms flop into linear forms as it were. No doubt this is related to the vibration of a bifilar system like the above, where the two ends are liable to vibrate alternately. When the average currents approach the order of 10^{-4} am., the bands became waves for all periods not excessively high or low.

[1] *Washington, Carnegie Inst., Pub.*, No. 149, pt. 3, § 123–125, 1914; cf., *Amer. J. Sci., New Haven*, **3**, 1897, (107).